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Report on Impacts of the Alliant Energy – IES Baseload Electricity Efficiency Pilot Program

December 4, 2000

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Alliant Energy -- IES Baseload Electricity Efficiency
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EXECUTIVE SUMMARY

Beginning in May, 1998, the Iowa Weatherization Assistance Program and Alliant Energy-IES Utilities, partnered to implement a pilot program to reduce exceptionally high electricity consumption in low income households in Iowa. The pilot program, dubbed the Baseload Electricity Efficiency Pilot (BEEP), and was funded by Alliant Energy and is patterned after Duquesne Light Company's Smart Comfort Program.

BEEP pilot program installed electricity efficiency measures in 57 households in Iowa between June, 1998 and April, 1999. The program was implemented by two of the agencies that install measures for the Iowa Weatherization Assistance Program (IWAP). Measures installed included refrigerator and freezer replacements/removals, and fuel switching from electric to gas or propane water heaters. Minor measures included additional compact fluorescent lighting, fans, clothes lines, and miscellaneous measures identified by the auditor on-site.

In addition to installing efficiency measures, a major objective of the program was to conduct broad-sweeping client education. In cases where the client was in arrears, the program sought to develop a payment plan to help repay the client's debt.

Major refrigeration appliances were installed if the daily consumption exceeded 5 kWh per day for refrigerators and 4 kWh per day for freezers. Daily consumption was extrapolated from a metering consumption for a 1-2 hour period which took place during the energy audit.

This evaluation reports on energy and client savings from the program, specifically:

- BEEP program energy and client savings;
- Major measure savings, including refrigerator and freezer replacements/removals, and water heater fuel switching savings;
- Assessment of the appropriate consumption threshold to use when evaluating the potential cost-effectiveness of replacing refrigeration appliances.

This evaluation uses both short-term (metered) and long-term (billing analysis) approaches to assess energy impacts. Existing refrigeration appliances that met the replacement thresholds were metered for a period of 3-7 days during the summer of 1998. The metering was repeated during the heating season. The replacement appliances were also metered during the heating season and during the summer of 1999. Ambient temperature readings were logged during all metering periods.

The metering data was used to develop models of energy consumption for all of the refrigeration appliances that were removed, replaced, or installed by the program.

In addition to metering, we conducted a fuel consumption analysis of the households. The modeled energy consumption was subtracted from whole-house impacts, leaving the net impacts of education, miscellaneous measures, and water heater fuel switching measures.

Summary of Findings
A total of 75 households were visited by BEEP personnel. The BEEP pilot successfully installed more than $66,000 in energy efficiency measures. These included 40 refrigerators, 19 freezers, and 16 water

heater fuel switches. Clients received energy education as well as numerous other measures suited for their particular energy efficiency needs. Measures were installed in 57 households.

Refrigerator and Freezer Replacement Savings

- Refrigerator and freezers exchanges saved an average of 1,327 (1,139 to 1,515)[1] kWh and 978 (834 to 1,122) kWh respectively. The average first year client savings from refrigerator exchanges was $108 ($93 to $123), and for freezers was $80 ($68 to$92). The average cost of new appliances was $689 for refrigerators and $399 for freezers. The appliance exchanges were cost-effective, providing mean savings-to-investment ratios (SIRs) of 1.8 (1.5 to 2.1) and 2.1 (1.8 to 2.4), respectively.

- Modeled impacts suggest that for every 100 households visited by a program similar to BEEP, 42 households would receive refrigerators and 23 would receive freezers (note: this assumes targeting households based upon high electricity consumption.) This translates into an average first-year savings of $75 per household for all households visited by the BEEP program. For comparison, first-year savings for the average IWAP participant, considering all households visited by IWAP personnel, is $183 per household in Iowa.

- Future program impacts would be optimized using a minimum threshold of 4.2 kWh for refrigerators and 2.6 kWh for freezers. The pilot program used 5 kWh per day for refrigerators and 4 kWh per day for freezers. If utility funds are used to replace major refrigeration appliances, then these might be subject to the more restrictive societal cost test used in Iowa. Higher thresholds should be calculated for these instances.

- Short-term metering should be conducted for a period of not less than 2 hours.

Education and Miscellaneous Measure Savings

The whole-house fuel consumption analysis points to savings for education and miscellaneous measures on the order of 682 (-459 to 1,859) kWh. The wide range of uncertainty stems from our small sample size. Assuming our median value for savings is representative of typical household savings for this high-use population, then our analysis suggests that education and miscellaneous measures are cost-effective as long as the average costs per household do not exceed $60 per household, even if the impacts persist for only a single year.

Water Heater Fuel Switching Savings

The fuel consumption analysis results show that typical fuel switching installations saved 2,175 (409 to 5,674) kWh per year, and increased natural gas use by 197 (-432 to -60) therms per year. Based upon these estimates, water heater fuel switching is borderline cost-effective from a client bill perspective. The first-year client savings were $87 (-201 to $498). The net lifetime client bill savings was $775 ($-1890 to $4,407), resulting in an SIR of 1.1 (-2.5 to 6.2).

Twenty-one percent of households visited by BEEP auditors received a water heater replacement from electricity to natural gas or propane. Savings from water heater fuel switching averaged $17 per household when averaged across all households participating in the BEEP program.

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[1] The 90% confidence intervals are shown in parentheses, i.e., we are 90% certain that the true population mean falls within the range defined by these values.

Program Design Recommendations

- Existing refrigeration appliances should be metered for a minimum of 2 hours.

- Replacement thresholds can be reduced to 4.2 kWh and 2.6 kWh for refrigerators and freezers, respectively. Appliances funded by Alliant Energy-IES which must pass the Iowa societal cost test should use the limits of 6.1 kWh and 3.7 kWh for refrigerators and freezers, respectively.

- Electricity savings from education and miscellaneous measures averaged 682 kWh (-459 to 1,859), however the savings were statistically indistinguishable from zero at 90% confidence. We recommend that they be continued, especially for these high-use households where better understanding of the costs and savings of these measures could lead to behavioral changes in discretionary energy use.

- Water heater fuel switching offers clients significant savings and should be considered for implementation in a full-scale program.

- The cost-effectiveness of installing extremely highly efficient refrigerators should be considered. Appliances installed through BEEP were standard higher-efficiency models offered by local vendors

- The cost-effectiveness of measures addressing other large end-uses such as clothes washing and drying, and dehumidification should be reviewed to determine if these measures could be added to the program.

1. SUMMARY OF THE BASELOAD ELECTRICITY EFFICIENCY PILOT PROGRAM

Introduction

Beginning in May, 1998, the Iowa Weatherization Assistance Program and Alliant Energy-IES Utilities, partnered to implement a pilot program to reduce exceptionally high electricity consumption in low income households in Iowa. The pilot program, dubbed the Baseload Electricity Efficiency Pilot (BEEP), and was funded by Alliant Energy and is patterned after Duquesne Light Company's Smart Comfort Program.

The program was implemented by two of the agencies that install measures for the Iowa Weatherization Assistance Program. BEEP provided major measures such as refrigerator and freezer replacements/removals, and fuel switching from electric to gas water heaters. Minor measures included additional compact fluorescent lighting, fans, clothes lines, and miscellaneous measures identified by the auditor on-site.

In addition to installing efficiency measures, a major objective of the program was to conduct broad-sweeping client education. In cases where the client was in arrears, the program sought to develop a payment plan to help repay the client's debt.

This evaluation includes assessments of energy and client savings from the program, specifically:

- BEEP program energy and client savings;
- Major measure savings, including refrigerator and freezer replacements/removals, and water heater fuel switching savings;
- Assessment of the appropriate consumption threshold to use when evaluating the potential cost-effectiveness of replacing refrigeration appliances.

This evaluation uses both short-term (metered) and long-term (billing analysis) approaches to assess energy impacts.

Program Design

The program was designed to reduce the electricity consumption for low income households with large electricity bills and arrearages. Customers receiving energy assistance and having arrearages were ranked according to arrears. After contacting the prospective customers, an auditor from one of two community action agencies met with the client. Large appliance replacements formed the cornerstone of this program's potential impacts, consequently those households who could benefit from the removal of eligible refrigeration appliances or by a switch from electric water heater to gas or propane water heater were eligible.

Refrigeration appliances were metered to determine their eligibility for replacement. The auditor placed an energy meter on the appliance and logged consumption for a period of one to two hours. The consumption was extrapolated to a daily total: if a refrigerator used at least 5 kWh per day or a freezer used at least 4 kWh per day, then it was eligible for replacement or removal.

Measures Installed

A total of 40 refrigerators and 19 freezers were installed in 52 households, at a total appliance cost of $35,409.

The water heaters in fourteen households were switched from electricity to natural gas and two switched to propane (note: eleven of these also received refrigeration appliances). In all, sixteen water heaters were switched from electricity to either natural gas or propane at a total cost of $11,314.

Table 1 provides a breakdown of all measures installed by the program.

Table 1.1

Measure		Number of Households	Number of Items	Total Cost	Per Household Receiving the Measure	
					Average Household Cost	Average Cost per Item
Refrigerator	Replacement	40	40	$27,884	$697	$697
	Removal	7	7	$0		
	Replace with Freezer	1	1	$349	$349	$349
Freezer	Replacement	18	18	$7,176	$399	$399
	Removal	0	0			
Water Heater Fuel Switch	Electric to natural gas	14	14			
	Electric to propane	2	2			
	Total	16	16	$11,314	$707	$707
CFL Lighting	60 watt equivalent	29	143	$1,754	$60.5	$12.26
	100 watt equivalent	13	19	$247	$19.01	$13.01
Fan		6	7	$151	$25.17	$21.57
Clothes Line		5	5	$120	$24.00	$24.00
Efficient Showerhead		1	1	$2	$2	$2
Waterbed Mattress Pad		6	10	$135	$22.50	$13.50
Miscellaneous Repair		2	2	$63.50	$31.75	$31.75
Total Materials Cost				$49,196		
Admin and Support				$17,029		
Total Costs				$66,224		

Organization of this Report

We assessed energy impacts using a two-pronged approach. We metered consumption for existing and replacement refrigeration appliances to obtain reliable estimates of the impacts of these measures. Those results are discussed in Section 2, Assessment of Refrigerator and Freezer Energy Savings.

Next, we conducted an analysis of changes to whole-house fuel consumption. This provided an assessment of the combined impacts of refrigeration appliances, client education, and miscellaneous measures installed by BEEP. We detail that analysis in Section 3, Assessment of Education and Miscellaneous Measure Savings.

Section 4, Short-Term Metering Intervals and Thresholds, presents an assessment of the duration of short-term metering intervals and thresholds to assure cost-effective refrigeration appliance replacements.

Appendix A provides an expanded discussion on the uncertainty analysis discussed in Section 3, Assessment of Education and Miscellaneous Measure Savings.

2. ASSESSMENT OF ENERGY AND CLIENT BILL SAVINGS FROM REFRIGERATOR AND FREEZER REPLACEMENTS AND REMOVALS

This section discusses the approach to metering the appliances, the results of metering energy consumption for the refrigerators and freezers that were replaced or removed for the BEEP pilot program, and extrapolation of the metered data to annual fuel consumption and savings.

Analytic Approach

Refrigeration consumption varies by season, day of the week, and from recurring daily events in addition to (random) periods of higher or lower consumption.

Seasonal variations in energy consumption are driven by higher temperature and relative humidity during the warmer months of the year, primarily from:

- larger temperature differential between room temperature and the refrigerated space,
- the use of sweat-reduction heaters to reduce the condensation on the exterior surfaces,
- more humid conditions, resulting in greater energy consumption for defrost cycles, and
- reductions in condenser efficiency at higher ambient temperatures.

Consumption varies during the week according to weekday/weekend occupancy. On an intraday basis, consumption fluctuations are attributable to:

- defrost cycles and
- periodic access during mealtime.

Large intraday, intraweek, and seasonal variability in consumption of refrigeration appliances make it impractical to project the annual energy consumption using short periods of metered data. Although we could meter consumption for an extended period of time (as much as one year pre and one year post), this is an expensive method requiring large numbers of meters.

Instead, we used a linear regression approach to relate energy consumption and room temperature. Energy consumption and temperature data were logged over a wide range of temperatures. This was necessary to allow us to establish the relationship between temperature and energy consumption. For the appliances that were slated for removal or replacement, these data were collected for a period of several days during the summer months (in 1998), and again for several days after the heating season had begun, but prior to installing the replacement appliances. The replacement appliances were monitored similarly, for a period of several days after replacement during the heating season, and another several days during the summer months (in 1999).

Metering Protocol

Refrigeration appliances were metered for two purposes: 1) to establish if the electricity consumption of the existing units was high enough to assure a cost-effective replacement, and 2) to collect enough data to assess the annual consumption of the existing and replacement appliances.

To establish electricity consumption of the existing units, the auditor placed an energy meter on the appliance and logged consumption for a period of one to two hours. The consumption was extrapolated to a daily total: if a refrigerator used at least 5 kWh per day or a freezer used at least 4 kWh per day, then it was eligible to be replaced.

The energy consumption of a total of 83 refrigerators and 42 freezers in 75 households were collected for approximately two hours. Overall, forty refrigerators and nineteen freezers were installed to replace units which met the screening thresholds. Seven refrigerators were removed without being replaced. Our evaluation determined that three of the refrigerators and two freezers that were replaced were marginally below the thresholds, but were erroneously scored as meeting the cutoff. One refrigerator with a broken door, also below the threshold, was replaced. In one case, a refrigerator was exchanged for a freezer.

In order to estimate the annual consumption of the existing and replacement units, we logged the hourly energy consumption using Brultech 1200 true-power meters for a period of 3 to 7 days. In addition, we logged the room temperature at 15 minute intervals using Onset temperature loggers. These data were collected during summer and winter (heated) periods for each of the existing appliances which were removed or replaced as well as for the replacement units themselves.

Models of Refrigeration Appliance Energy Consumption

We considered several regression models of refrigerator energy consumption which related consumption with the ambient temperature[2]. During this process, it became clear that while temperature was an

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[2]We considered several linear regression models. Our initial models correlated hourly consumption with temperature and hour of the day:

Hourly consumption $= b_0 + b_1*$average hourly temperature

These models were poorly defined as temperature accounted for a relatively small portion of intraday variability. Other factors, such as defrost cycles and periodic (mealtime) access and random events accounted for most of the intraday variability.

Next, we specified a model that would account for regular, recurring impacts, such as periodic defrost cycles and mealtime access. This model took the following form:

Hourly consumption $= b_0 + b_1*$ hour 1average hourly temperature $+ .... + b23 *$ hour 23 average hourly temperature

This approach can lead to very good models for appliances with defrost cycles that recur over periods that are evenly divisible into 24 (2,3,4,6, 8, and 12 hour defrost intervals), and for those with regular periods of mealtime access. Unfortunately, these models suffer from a couple of problems:

1) the defrost cycles often drifted from one hourly period to another over the metering period, a problem which was further exacerbated by power outages or intermittent disconnection of the energy meters by the clients (this occurred rather frequently for a handful of the appliances); and

2) this method required separate models for winter and summer periods as the defrost cycles most certainly drifted over the intervening months. The two separate models must be weighted for the proportion of the year which they represent, i.e., the summer model would be best suited to only the two or three warmest months of the year, the winter model for approximately a five month heating season, and either model for the shoulder months between.

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important factor in consumption, it explained only a fraction of the intraday variability in consumption. Other factors, such as defrost cycles and periodic (mealtime) access accounted for most of the intraday variability. While important for assessing consumption at any point during the day, the impact of these primarily intraday factors does not vary greatly on a day-to-day or seasonal basis. Consequently, they are not particularly useful parameters for modeling annual consumption.

We specified a model based on daily consumption:

$$\text{Daily consumption} = b_0 + b_1 * \text{average daily temperature}$$

We had at least 5 observations to develop models for 58 of the existing appliances and 54 of the replacement appliances. Table 2.1 summarizes the regression diagnostics and provides a comparison of the modeled annual consumption with an extrapolation based upon the average summer and winter metered consumption. The adjusted R^2 indicate that the models explain more than 50% of the variability in most cases. For those models with poorer fits, the extrapolated annual consumption compare favorably with the modeled consumption, suggesting that the models for these appliances are not grossly overstating or understating annual consumption.

Table 2.1. Summary of Regression Model Fit

Unit ID	Location	n	Adj R-squared	Pre Modeled Annual Cons (kWh)	Pre Extrapolated Annual Cons (kWh)	n	Adj R-squared	Post Modeled Annual Cons (kWh)	Post Extrapolated Annual Cons (kWh)
2.10	heated	5	0.45	2,265	2,628			#N/A	#N/A
3.10	heated	10	-0.03	994	1,000	13	0.82	743	940
4.10	heated	14	0.45	1,344	1,712	13	-0.07	716	674
6.10	heated	15	0.22	1,116	1,161	14	0.77	735	864
7.10	heated	12	-0.10	2,655	2,663	9	0.93	941	809
8.10	heated	13	0.07	1,569	1,505	13	0.28	613	715
9.10	heated	14	0.48	2,378	2,356	13	0.55	728	717
14.20	summer-exposed basement	19	0.99	#N/A	#N/A	15	0.85	#N/A	#N/A
16.10	heated	10	0.75	2,053	2,177	15	0.53	501	627
17.10	heated	14	0.72	1,684	1,516			#N/A	#N/A
17.20	semi-exposed	13	0.78	1,199	1,278			#N/A	#N/A
18.10	heated	15	0.77	1,471	1,519	13	0.75	836	884
18.20	unheated basement	15	0.52	1,271	1,277			#N/A	#N/A
19.20	heated	9	0.90	1,002	1,051	14	0.67	355	385
20.10	heated	9	0.79	1,846	1,823	14	0.66	1,226	1,241
20.20	unheated basement	9	0.96	1,293	1,354	14	0.59	420	417
21.10	heated	9	0.59	2,926	2,771	14	0.61	782	741
23.10	heated	9	0.94	3,365	3,718	10	0.03	849	912
28.10	heated	14	0.65	3,790	3,829	14	0.10	773	734
32.10	winter heated basement	10	0.89	1,670	1,537	12	0.88	468	413
33.10	heated	9	0.91	2,373	2,378	10	0.60	584	591
33.20	heated			#N/A	#N/A	8	0.85	321	388
34.10	heated	9	0.96	2,530	2,806	11	0.87	611	592
35.10	heated	12	0.63	1,113	1,333	12	0.47	550	581
39.10	heated	8	0.54	1,426	1,467	10	0.12	749	752
41.10	heated	9	0.87	1,859	2,028	12	0.80	532	519
41.30	heated			#N/A	#N/A	12	0.65	495	471
42.20	unheated basement	9	0.08	756	1,045			#N/A	#N/A
43.10	heated	10	0.94	2,227	2,581	12	0.86	570	596
44.10	heated	9	0.50	1,974	2,211	12	-0.05	779	837
45.10	heated	8	0.76	2,056	2,942	12	0.79	602	780
46.10	heated	13	0.83	2,356	2,327	14	0.61	628	544
46.20	unheated basement	13	0.91	1,569	1,600	14	0.97	326	297
47.10	heated	10	0.90	1,704	2,064			#N/A	#N/A
48.10	heated	9	0.09	2,639	2,576	14	0.00	965	933
49.10	heated	9	0.76	1,707	1,925	13	0.55	667	719
49.20	winter heated basement	9	0.56	1,871	2,516	13	0.34	295	343
50.10	heated	9	0.66	1,455	1,552	11	0.24	684	682
50.20	unheated basement	10	0.96	1,243	1,256	11	0.77	366	339
51.10	semi-exposed	9	0.81	1,963	2,207	12	0.98	297	287
52.20	winter heated basement	9	0.94	1,227	1,224	14	0.86	362	356
54.20	heated	10	0.98	1,392	1,305	11	0.45	510	489
55.10	heated			#N/A	#N/A	11	0.24	838	863
58.10	heated	12	0.14	2,087	2,098	12	0.27	629	602
61.10	heated	9	0.74	1,915	2,034	8	0.90	733	644
62.10	heated	9	0.92	1,137	1,321	13	0.83	807	767
62.30	heated	9	0.95	1,633	1,999	12	0.61	437	451
63.10	heated	14	0.01	1,010	1,037	13	0.32	713	750
67.10	heated	12	0.39	1,028	923	13	-0.09	#N/A	#N/A
67.20	heated	12	0.90	1,488	1,531	14	0.67	660	651
68.20	heated	9	0.97	1,520	1,544			#N/A	#N/A
70.10	heated	10	0.67	3,847	3,796	13	0.68	792	672
72.10	heated	13	0.79	1,822	1,854	14	0.94	933	926
73.10	heated	13	0.96	2,803	2,728	13	0.90	763	528
73.20	semi-exposed	11	0.97	983	825	13	0.74	396	317
74.10	heated	8	0.79	2,366	1,596	13	0.83	1,094	850
78.10	heated	12	-0.08	1,601	1,526	13	-0.03	486	498
80.20	semi-exposed	10	0.97	821	910	14	0.29	326	464
81.30	semi-exposed	5	0.95	1,437	1,554	13	0.98	395	412
82.20	unheated basement	10	0.91	1,209	1,238	11	0.85	634	571

In order to project the annual consumption using the regression models, it was necessary to develop annual temperature profiles. Our field measurements of temperature included periods during June-August (1998 and 1999), December 1998, and February 1999. We used these data to project the daily average temperatures for each month by fitting a sine curve to the temperature data for each month, and selecting the sine curve that minimized the square of the difference between the data and the sine curve.

We developed temperature profiles for four major installation environments, including heated space, winter-heated basement, unheated basement, and semi-exposed (breezeway, garage, etc.) One appliance was afforded its own group: the basement space was unheated in winter, but warmed up with exterior temperatures during the summer: we speculated that the homeowner used a whole house fan, and pulled air through the basement area to pre-cool air entering the house.

Figure 2.1 shows the temperature data and the fit curve for each of the temperature groups.
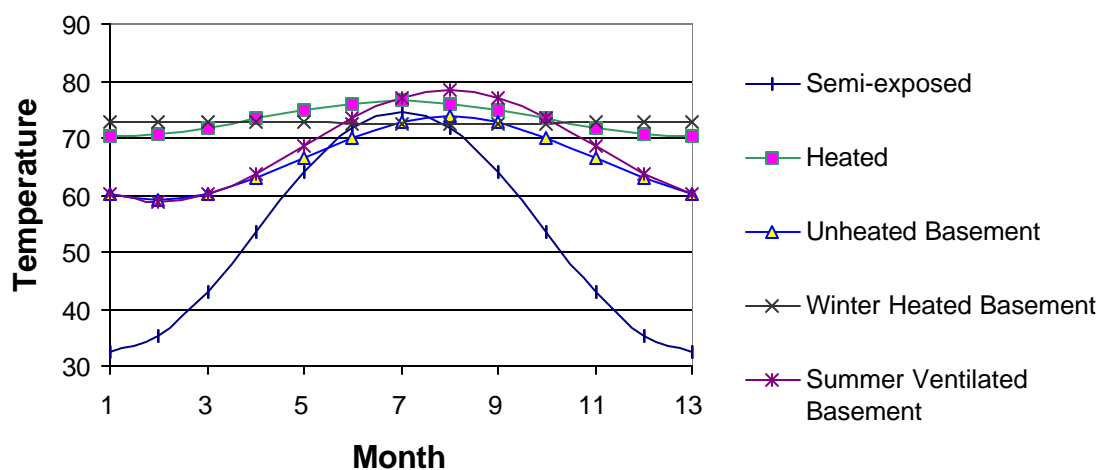
Figure 2.1. Annual temperature profiles

Service Lifetime of Replacement Appliances
The service lifetime is a key parameter for assessing the cost-effectiveness of the replacement appliances. Refrigeration appliances have service lifetimes of approximately 20 years, however it is extremely unlikely that the old, inefficient units replaced by BEEP would last another 20 years. Rather, it is probable that the appliances will be replaced with new or used appliances during that timeframe.

As part of the BEEP protocol, the auditors asked clients whether they thought they would replace aging refrigeration appliances with new or used models. Of the 58% that responded, 45% stated that they would replace their appliances with new units, 55% stated they would replace them with used appliances. While this question in no way assures us of future actions, it is indicative of the clients' intentions. In order to estimate a typical service lifetime for replacement units, we assumed the following:

- the existing appliances would remain in service for another 10 years without intervention by the BEEP program
- 45% would replace these units with new refrigerators, with approximately the same consumption as units provided by BEEP
- 55% would replace the units with used units of approximately the same efficiency as those they currently owned.

Given these assumptions, the period of savings for appliances replaced by BEEP would be 10 years for clients who would replace their existing unit with a new unit, and 20 years for those who would have replaced their existing appliances with used ones. The weighted average service lifetime is 15.5 years.

Results

Using the models of consumption and our typical temperature profiles, we calculated the pre/post consumption, energy and bill savings, the savings to investment ratio (SIR) and the payback period for various groups of our data for which we had enough meter data in the pre and post periods to model consumption.

Table 2.2 summarizes our results.

Table 2.2. Summary of Appliance Savings

			All Households n = 45		All Appliances n = 54		Refrigerators n=39				Freezers n=15			
			kWh	90% CI	kWh	90% CI	kWh	90% CI	kW	90% CI	kWh	90% CI	kW	90% CI
Energy Consumption	Mean	Pre	2,186	134	1,822	149	1,990	186	0.259	0.024	1,389	126	0.190	0.019
		Post	712	40	593	54	663	66	0.098	0.007	411	39	0.057	0.005
		Savings	1,474	118	1,229	146	1,327	188	0.177	0.025	978	144	0.133	0.022
	Median	Pre	2,056	209	1,651	184	1,915	251	0.261	0.035	1,392	182	0.175	0.019
		Post	713	45	612	63	713	63	0.090	0.008	395	52	0.057	0.006
		Savings	1,343	171	1,039	193	1,202	271	0.180	0.044	997	184	0.110	0.026
Client Savings			$	90% CI	$	90% CI	$	90% CI			$	90% CI		
First Year	Mean		120	10	100	12	108	15			80	12		
	Median		119	14	94	16	104	22			72	15		
Lifetime (Nominal)			$	90% CI		90% CI	$	90% CI			$	90% CI		
	Mean		1,862	155	1,555	184	1,677	238			1,237	182		
	Median		1,845	217	1,453	247	1,605	341			1,118	233		
Lifetime (Discounted)			$	90% CI	$	90% CI	$	90% CI			$	90% CI		
	Mean		1,359	113	1,134	134	1,239	176			849	125		
	Median		1,208	142	1,012	172	1,076	228			793	165		
Appliance Cost			$	90% CI	$	90% CI	$	90% CI			$	90% CI		
	Mean		704	41	600	41	689	44			399	23		
	Median		639	73	550	27	629	77			395	72		
Savings to Investment Ratio (SIR)				90% CI		90% CI		90% CI				90% CI		
	Mean		1.93	0.25	1.89	0.25	1.80	0.30			2.13	0.33		
	Median		1.89	0.31	1.84	0.29	1.71	0.39			2.01	0.35		

Note: this SIR accounts for appliance costs only (not metering costs or program administration costs)

The average household energy consumption for refrigeration appliances replaced through BEEP was 2,186 (±134) kWh[3], with an operating cost of approximately $177 per year. After replacement (or

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[3] Values in parentheses are the 90% confidence interval. The confidence interval represents the range for which we are 90% sure contains the true population mean (or median).

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removal), the average household energy consumption for these appliances was 712 (±40) kWh, a 66% reduction. Household energy savings averaged 1,474 (±118) kWh, providing the client an average first year savings of $120(±10). The appliances cost an average of $704 (±41) per household. Overall, the house-level savings to investment ratio (SIR)[4] averaged 1.93 (±0.25).

The statistics for households are higher than for individual appliances as some households received more than one appliance, and in some cases appliances were removed without being replaced.

The energy consumption of refrigerators replaced through BEEP averaged 1,990 (±186) kWh per year prior to replacement, and 663 (±66) after replacement, a 67% reduction. First year client bill savings averaged $108 (±15) per refrigerator. The refrigerators cost an average of $689 (±44). The mean SIR for refrigerators replaced through BEEP was 1.80 (±0.30).

The energy consumption of freezers replaced through BEEP averaged 1,389 (±126) kWh per year prior to replacement, and 411 (±39) after replacement, yielding a 70% reduction in energy use. First year client bill savings averaged $80 (±12) per freezer replaced. The freezers cost an average of $399 (±23). The mean SIR for freezers replaced through BEEP was 2.13 (±0.33)

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[4] The lifetime savings was based upon a weighted average life of 15.5 years and a 5% social discount rate.

3. ASSESSMENT OF SAVINGS FROM EDUCATION AND MISCELLANEOUS MEASURES

The metering approach discussed in the previous section provides reliable estimates of savings for the refrigeration appliances installed through BEEP. BEEP activities extended beyond refrigeration appliance measures, however, by providing client education and installing a wide range of measures (see Table 1.1) . In order to determine the impacts of the education and miscellaneous energy savings measures, we assessed the change in consumption for the whole house, and subtracted savings for refrigeration appliances. Water heater fuel switching resulted in substantial impacts: we were able to disaggregate those savings from the aggregate of other measures.

We assessed changes in whole-house electricity and natural gas fuel consumption for houses treated by BEEP, and compared those results with changes in fuel consumption for other low-income houses in same geographic region. The net impacts between the BEEP and the comparison group houses are attributed to BEEP participation.

Assessment of Whole-House Fuel Consumption Impacts

We defined our pre-treatment period as the one-year period beginning with billing cycles ending 5/15/1997, and our post period as the one year period beginning with billing cycles ending 5/15/1998. We used the same time frame for assessing changes in the comparison group.

We analyzed the 'normal' fuel consumption in each period using the Princeton Scorekeeping Method, commonly known as PRISM. Using piece-wise linear regression methods, PRISM separates the part of energy usage that fluctuates with changes in ambient temperature from constant (baseload) energy usage. The result is a model of fuel usage based upon known fuel consumption and temperatures during the study period. The model is applied to long-term normal temperatures for the local region[5] to give the normalized annual consumption (NAC), which is the primary measure of energy usage reported by PRISM[6]. Fuel savings for an individual house are calculated as the difference between the NAC prior to and after weatherization. When calculated for a large group of houses, the mean (or median) of the savings provides a well-defined estimate of change in energy usage for those houses.

Treatment and Comparison Groups

The treatment and comparison population consisted of all of the Low-Income Energy Assistance Program clients served by the participating agencies. For each agency, the households were ranked according to energy consumption, and were split into comparison and treatment populations, such that those with odd

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[5] We used weather zones central to each agency, including Marshalltown and Cedar Rapids, Iowa.

[6] In addition to measuring fuel consumption (NAC), PRISM provides three indicators of energy usage. These are the normalized annual heating consumption (NAHC), the baseload energy consumption, and the balance point of the house. The NAHC is the part of annual consumption that fluctuates with changes in temperature. The baseload estimate is usage that stays constant month-to-month throughout the year. The balance point is an estimate of the temperature at which heating fuel is required for a house.

NAC is the primary measure of fuel usage reported by PRISM; the others are generally used as indicators of the reliability of the PRISM models rather than as actual measures of energy consumption. PRISM cannot separate non-weather sources of seasonal energy use temperature variations. These factors tend to have noticeable influence on the NAHC, baseload and balance point results, but have relatively little impact on the estimates of NAC.

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numbers according to rank were placed in the treatment population, even numbers according to rank in the comparison population.

Seventy-five households with the highest annual electricity usage in the treatment population were visited for the BEEP program. Fifty-seven households received education and measures: these households comprise our treatment group. We removed from the analysis the eighteen houses that were visited by BEEP auditors but which received no measures.

To develop a comparison group, we ranked the comparison population households according to electricity consumption and selected the seventy-five households with the highest consumption. This is essentially the same process as was used during selection for BEEP treatment, with one difference: we excluded households that participated in the IWAP at any time during the study period.

Treatment Group Sample Attrition

We found that we had sufficient billing data to run PRISM for 49 of the 57 treated households, however 27 of these also received weatherization at some point during the pre, post, or BEEP treatment periods. We removed these from our analysis. We had incomplete metering data for two of the remaining 22 households, which we also removed. This left us with 20 households treated solely by the BEEP program for which we have PRISM and appliance energy savings data. Six of these also received water heater fuel switches.

In summary, we were left with 20 treatment houses and 75 comparison group houses which we used to assess non-appliance impacts of the BEEP program.

Weather Data

We used weather zones central to each agency, including Marshalltown and Cedar Rapids, Iowa.

Methodology for Assessing Non-Appliance BEEP Program Impacts

We calculated the non-appliance impacts for each household as the total household savings less the total appliance savings, where individual appliance savings were each calculated according to the regression models we detailed in the previous section of this report. We did this for each house in the comparison group as well as the treatment group, and ascribed the net impacts of these two groups to the BEEP program.

This methodology provides a measure of program-induced impacts, however it does not account for uncertainty in either the sample or in the PRISM and regression models. Sampling uncertainty refers to uncertainty in knowing how well the energy use and savings for the houses in the study sample reflects the energy use and savings for houses in the entire population. The smaller the sample, the greater the sampling uncertainty: our study samples are relatively small. We assessed the sampling uncertainty with a bootstrapping analysis, i.e., we randomly sampled houses (with replacement) to give the same overall sample sizes, and recalculated the net energy consumption and savings. This process was repeated 10,000 times in our analysis.

Another source of uncertainty derives from our use of PRISM and regression models. The estimate of NAC from PRISM and the coefficient and constants from our regression models of appliance energy consumption each have an associated uncertainty. Assuming a normal distribution for the uncertainty in NAC and on the regression parameters for the models of each appliance, we generated a different, albeit probable, value of energy use for each house and appliance in the pre- and post-BEEP periods. We recalculated the energy use and savings for each house using the simulated data. From these, we calculated the net energy consumption and savings as described above. This process was carried out concurrently with the bootstrap resampling (10,000 iterations).

We assessed the mean, median, and confidence intervals directly from the results, using the 5th and 95th percentiles of the results for the confidence intervals.

Results

Table 3.1 summarizes our results[7]. We've provided both mean and median values, however the mean results should be used only after careful consideration of the small sizes of samples: *it is our judgement that the median impacts are more reliable indicators of impacts for this study and we reference median values throughout the discussion of this section*.

The pre-program NAC for the comparison group exceeded that of the treatment group by 19% for BEEP households that received only appliances, and 10% for households that received water heater fuel switches. The higher usage in the comparison group suggests that changes in the NAC for the comparison group (i.e., comparison group savings) would be proportionately higher. To correct for this disparity, we scaled back the comparison group savings proportionally for the appliance-only and fuel substitution/appliance groups respectively during the calculation of the net program impacts.

The key objectives of this analysis are to determine the energy savings from education/miscellaneous measures and the impacts of fuel switching. We found that education/miscellaneous measures saved 682 kWh for households not receiving water heaters: we are 90% confident that the true population savings falls within the range from -489 to +1,859 kWh. Households converted to natural gas water heating saved 2,856 kWh per household (ranging from 1,362 to 6,384 kWh at 90% confidence). The water heater fuel switch accounted for 2,175 kWh (409 to 5,674 kWh), or 79% of the electricity saved in these households. Natural gas use *increased* by 197 therms (60 to 432 therm increase at 90% confidence) in households that were switched to natural gas.

Its important to recognize that even though we determined substantial savings for education and miscellaneous measures, the savings for these measures were statistically indistinguishable from 0 in this analysis. This was due to the wide band of uncertainty around our results, an artifact of small sample size, accentuated by the sample attrition from weatherization activities during the study period. The exception was water heater fuel switching, where we did discern statistically significant electricity savings and natural gas increases.

Water Heater Fuel Switching Cost-effectiveness

We found that water heater fuel switching is borderline cost-effective from a client bill perspective. Assuming the following:
- client fuel costs are $0.09 per kWh, $0.55 per therm over the lifetime of the water heater
- 2,175 (409 to 5,674) kWh per year saved, 197 (-432 to -60) therms per year increased
- 12 year lifetime
- 5% discount rate
- $707 per water heater switch

First-year client savings are $87 (-201 to $498 at 90% confidence). The net lifetime client bill savings are $775 ($-1890 to $4,407), resulting in an SIR of 1.1 (-2.5 to 6.2).

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[7] For those interested in the relative contribution of sampling and model uncertainty to the overall uncertainty, we have provided two additional summaries in Appendix A, showing separate results for each type of uncertainty separately.

Table 3.1

Mean Value Results	Whole House Fuel Consumption				Savings							
	Pre-Period NAC		Post-Period NAC		Whole House		Refr/Freezer		Combined Educ/Misc Water Heater Mea		Water Heater Only	
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=75)	14,950	14,227 to 15,714	14,298	13,340 to 15,349	652	-79 to 1,445	0	0 to 0	652	-79 to 1,445		
Appliance only (n=14)	12,437	10,523 to 14,550	9,524	7,652 to 11,438	2,913	1,683 to 4,258	1,515	704 to 2,426	1,398	-5 to 2,898		
Water heater, some with appliances (n=6)	13,388	11,341 to 15,796	8,486	6,219 to 10,879	4,902	2,867 to 7,324	574	85 to 1,128	4,328	2,191 to 6,906		
Net Appliance-only savings					2,393	1,025 to 3,801	1,515	704 to 2,426	877	-635 to 2,436		
Net Water heater, some appliances					4,382	2,220 to 6,832	574	85 to 1,128	3,808	1,537 to 6,430	2,930	271 to 5,891
Natural Gas (therms)												
Comparison (n=75)	1,001	898 to 1,113	1,024	914 to 1,143	-23	-62 to 16	0	0	-23	-62 to 16		
Appliance only (n=14)	1,015	849 to 1,183	1,025	897 to 1,148	-10	-97 to 81	0	0	-10	-97 to 81		
Water heater, some with appliances (n=6)	1,033	663 to 1,419	1,297	958 to 1,633	-264	-418 to -130	0	0	-264	-418 to -130		
Net Appliance-only savings					8	-86 to 105	0	0	8	-86 to 105		
Net Water heater, some appliances					-246	-403 to -109	0	0	-246	-403 to -109	-254	-430 to -93

Median Value Results	Pre-Period NAC		Post-Period NAC		Whole House		Refr/Freezer		Combined Educ/Misc Water Heater Mea		Water Heater Only	
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=47)	14,097	13,384 to 14,757	13,703	12,435 to 15,013	541	-308 to 1,163	0	0 to 0	541	-308 to 1,163		
Appliance only (n=8)	11,847	10,606 to 13,501	8,936	6,432 to 11,958	2,379	1,773 to 3,596	1,237	812 to 1,997	1,113	-29 to 1,984		
Water heater, some with appliances (n=4)	12,811	10,313 to 15,878	8,777	4,656 to 11,476	3,946	2,433 to 7,079	323	0 to 1,176	3,288	1,835 to 6,678		
Net Appliance-only savings					1,948	1,221 to 3,342	1,237	812 to 1,997	682	-459 to 1,859		
Net Water heater, some appliances					3,515	1,942 to 6,750	323	0 to 1,176	2,856	1,362 to 6,384	2,175	409 to 5,674
Natural Gas (therms)												
Comparison (n=47)	926	845 to 1,000	928	777 to 1,032	-23	-53 to 27	0	0	-23	-53 to 27		
Appliance only (n=8)	1,034	800 to 1,242	1,031	858 to 1,188	-28	-108 to 75	0	0	-28	-108 to 75		
Water heater, some with appliances (n=4)	910	513 to 1,426	1,306	699 to 1,697	-225	-441 to -116	0	0	-225	-441 to -116		
Net Appliance-only savings					-10	-103 to 92	0	0	-10	-103 to 92		
Net Water heater, some appliances					-207	-435 to -100	0	0	-207	-435 to -100	-197	-432 to -60

4. SHORT-TERM METERING INTERVALS AND THRESHOLDS

This section presents an assessment of the duration of short-term metering intervals and thresholds to assure cost-effective refrigeration appliance replacements.

In this section, we address two issues related to short-term metering thresholds:

> 1) what is the appropriate length of short-term metering intervals to reasonably assure that each replacement is cost-effective; and

> 2) given various lengths of short-term metering periods, what is the appropriate threshold to maximize cost-effective program savings.

For the pilot program, refrigerators were replaced if the short-term consumption (logged for a 1-2 hour period) exceeded the equivalent of 5 kWh per day. Freezers were eligible for replacement using a 4 kWh per day threshold. These thresholds were selected to reasonably assure that replaced appliances would be cost-effective on an aggregate program basis. Our analysis presented in the previous section confirms that these thresholds are cost-effective for the aggregate program, but not all appliances that met the short-term threshold used 5 kWh per day on an annual basis.

Figures 4.1 and 4.2 show plots of the projected annual consumption extrapolated from the short-term meter readings and those calculated using the regression models. In some cases, the extrapolated short-term readings substantially overstated annual consumption.

Extending the short-term metering period would reduce the uncertainty in the projected annual consumption of any given appliance, as longer metering periods spread out random periods of greater/lesser use and the high use associated with defrost cycles and meal-time access. Reducing the uncertainty by extending the metering duration comes at a cost: if the short-term metering periods exceed approximately two hours, then a return trip to retrieve the meter becomes necessary. The IWAP estimates a cost of approximately $20 to return to a house to retrieve a meter. An additional cost would be for metering equipment as more meters would be required, but we believe that this additional cost would be negligible if the meters were used for several years.

By reducing the uncertainty in the projected annual consumption, the program could lower the eligibility thresholds without risking reductions in overall program cost-effectiveness. Lowering the eligibility threshold would increase the percentage of appliances replaced, increasing the number of clients benefiting from the program and minimizing lost opportunities to assist clients. Furthermore, increasing the percentage of eligible clients reduces the average cost of metering: IWAP estimates that it costs $15 to conduct each short-term metering assessment. For example, if 25% of appliances are eligible at a given threshold, the average cost of conducting the short-term metering for units found to be eligible is $60. If 75% are eligible at a lower threshold, the average cost is only $20.

In the remainder of this section we detail an analysis aimed at balancing the increased uncertainty of reducing the threshold and shorter metering periods while at the same time maximizing cost-effective program savings.
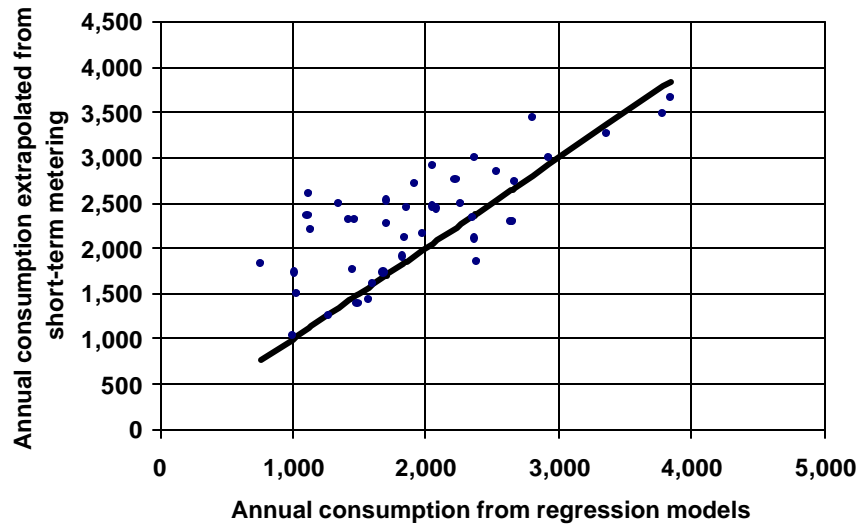
Figure 4.1 Annual consumption extrapolated from short-term metering vs. regression model consumption -- refrigerators
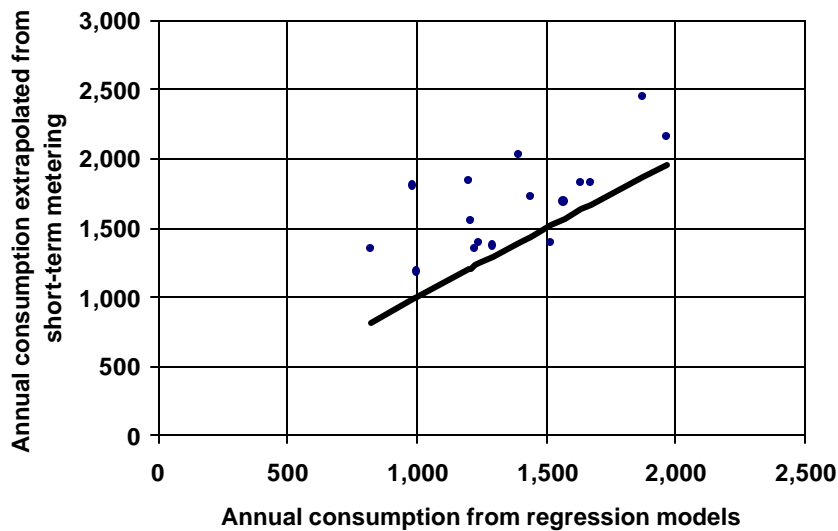
Figure 4.2 Annual consumption extrapolated from short-term metering vs. regression model consumption -- freezers

Methodology

We used a probabilistic analysis to assess whether any given appliance would meet a specific consumption threshold. Savings were calculated as:

Savings = probability of meeting threshold * (annual consumption - replacement appliance consumption)

The key variable in this equation is the probability that the consumption measured for any given period length will meet a specific threshold. The consumption rate varies throughout the day, and the longer the period of measurement, the less variability one would expect from one period to the next. We created 'virtual' short-term metering periods using our longer-term meter data (hourly data for several days in summer and winter periods). The metering periods included all possible periods starting no earlier than 8:00 a.m. and ending by 5:00 p.m. (the normal working day for the auditors) and lasting for 1, 2, 3, 4, 6, and 24 hours. The standard deviation of all the possible consumption periods for each of these period lengths provided the measure of variability.

Tables 4.1-4.3 show the short-term projected annual consumption, the annual consumption from our regression models, and the standard deviation of period consumption[8] for all appliances for which we had long-term data histories. A couple of things stand out in this table:

1) as expected, the variability is reduced with longer metering periods, evidenced by the smaller standard deviations as the periods get longer;

2) there is substantial variation in the standard deviation of the periodic consumption from one appliance to the next, even among appliances with approximately the same annual consumption.

3) generally speaking, the variability for freezers is less than for refrigerators of similar consumption.

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[8] The standard deviation shown is the average of the summer and winter standard deviations of consumption for each period. Simply taking the standard deviation for all periods without seasonal differentiation would have exaggerated the variability, because not only would the period-to-period variability be reflected, but also the variability in consumption from seasonal changes in room temperature.

Table 4.1. Summary of Variability of Existing Refrigerator Appliance Stock

Unit ID	Appliance Type	Annual Consumption Extrapolated from Short-Term Value (1)	Modeled Annual Consumption	Standard Deviation of Consumption for Various Short-Term Period Lengths (kWh)					
				1 Hour	2 Hours	3 Hours	4 Hours	6 Hours	24 Hours
42.2	refr	1,821	756	500	113	160	94	77	28
3.1	refr	1,041	994	304	273	242	205	142	52
63.1	refr	1,730	1,010	265	219	186	162	128	64
67.1	refr	1,503	1,028	314	258	219	194	162	43
35.1	refr	2,365	1,113	531	398	340	306	259	146
6.1	refr	2,608	1,116	673	513	354	266	230	109
62.1	refr	2,203	1,137	459	386	340	313	281	43
18.2	refr	1,243	1,271	134	68	52	48	41	32
4.1	refr	2,483	1,344	386	318	281	257	224	112
39.1	refr	2,323	1,426	630	496	406	345	271	58
50.1	refr	1,755	1,455	319	256	219	196	166	55
18.1	refr	2,310	1,471	543	433	351	294	208	62
67.2	refr	1,385	1,488	271	221	190	163	123	82
8.1	refr	1,439	1,569	124	77	67	59	50	25
78.1	refr	1,597	1,601	384	332	307	293	273	160
17.1	refr	1,729	1,684	481	393	343	300	230	56
47.1	refr	2,265	1,704	230	187	157	132	97	45
49.1	refr	2,523	1,707	355	262	214	181	140	35
72.1	refr	1,906	1,822	603	486	428	388	334	172
20.1	refr	2,108	1,846	376	310	285	266	239	81
41.1	refr	2,444	1,859	393	284	247	225	197	32
61.1	refr	2,703	1,915	386	299	266	242	206	110
44.1	refr	2,162	1,974	192	147	114	89	52	8
16.1	refr	2,455	2,053	420	366	333	309	278	168
45.1	refr	2,917	2,056	437	354	299	257	193	42
58.1	refr	2,434	2,087	827	538	431	363	250	78
43.1	refr	2,747	2,227	748	526	433	385	316	97
2.1	refr	2,498	2,265	547	460	415	383	344	163
46.1	refr	2,334	2,356	407	329	287	260	225	128
74.1	refr	2,102	2,366	717	578	497	435	349	204
33.1	refr	2,996	2,373	463	387	332	288	223	56
9.1	refr	1,851	2,378	108	65	48	37	19	13
34.1	refr	2,838	2,530	560	361	288	253	191	51
48.1	refr	2,286	2,639	140	115	103	94	84	36
7.1	refr	2,288	2,655	275	193	160	139	112	59
42.1	refr	2,736	2,665	454	354	296	248	174	44
73.1	refr	3,433	2,803	416	368	342	323	295	157
21.1	refr	2,996	2,926	495	393	327	290	240	167
23.1	refr	3,254	3,365	264	203	180	162	136	74
28.1	refr	3,491	3,790	421	365	331	303	265	160
70.1	refr	3,656	3,847	266	150	117	102	86	31

Table 4.2. Summary of Variability of Replacement Refrigerators

Unit ID	Appliance Type	Annual Consumption Extrapolated from Short-Term Value (1)	Modeled Annual Consumption	Standard Deviation of Consumption for Various Short-Term Period Lengths (kWh)					
				1 Hour	2 Hours	3 Hours	4 Hours	6 Hours	24 Hours
78.1	refr		486	142	121	107	96	80	36
16.1	refr		501	242	202	181	170	155	108
41.1	refr		532	195	131	114	101	86	39
35.1	refr		550	346	251	222	198	166	48
43.1	refr		570	248	203	171	147	119	40
42.1	refr		577	307	264	237	219	194	104
33.1	refr		584	317	216	181	156	129	45
45.1	refr		602	277	228	199	178	144	23
34.1	refr		611	214	171	146	132	110	35
8.1	refr		613	241	201	170	149	124	53
46.1	refr		628	225	184	157	139	116	25
58.1	refr		629	240	177	151	132	108	31
67.2	refr		660	213	171	149	135	113	35
49.1	refr		667	244	184	156	137	111	29
50.1	refr		684	280	216	181	158	127	46
63.1	refr		713	277	223	201	184	160	90
4.1	refr		716	237	195	169	151	125	43
9.1	refr		728	225	183	160	147	125	36
61.1	refr		733	281	225	193	173	147	46
6.1	refr		735	299	263	244	229	206	114
3.1	refr		743	299	256	232	214	188	76
39.1	refr		749	549	392	292	248	209	66
73.1	refr		763	257	212	192	182	166	94
28.1	refr		773	338	291	265	247	218	105
44.1	refr		779	418	341	303	286	255	128
21.1	refr		782	311	259	231	211	182	84
70.1	refr		792	329	285	260	243	218	125
62.1	refr		807	312	252	225	206	176	63
18.1	refr		836	269	229	208	192	168	80
55.1	refr		838	336	296	268	248	216	69
23.1	refr		849	332	287	263	245	216	63
72.1	refr		933	330	265	233	212	181	80
7.1	refr		941	312	263	242	227	202	45
48.1	refr		965	350	294	255	228	192	79
74.1	refr		1,094	315	249	221	205	184	106
20.1	refr		1,226	373	304	268	244	214	80

(1) Values in this column are blank for replacement appliances (no short-term metering was done on replacment appliances)

Table 4.3. Summary of Variability of Existing and Replacement Freezers

Unit ID	Appliance Type	Annual Consumption Extrapolated from Short-Term Value (1)	Modeled Annual Consumption	Standard Deviation of Consumption for Various Short-Term Period Lengths (kWh)					
				1 Hour	2 Hours	3 Hours	4 Hours	6 Hours	24 Hours
80.2	freezer	1,352	821	129	100	84	76	69	25
73.2	freezer	1,804	983	298	207	174	150	136	78
19.2	freezer	1,183	1,002	110	89	77	68	59	19
17.2	freezer	1,840	1,199	215	180	149	128	108	52
82.2	freezer	1,554	1,209	190	94	82	54	42	20
52.2	freezer	1,352	1,227	698	251	155	154	100	42
50.2	freezer	1,396	1,243	251	112	90	79	58	20
20.2	freezer	1,371	1,293	59	51	48	46	42	18
54.2	freezer	2,027	1,392	234	166	95	67	71	27
81.3	freezer	1,723	1,437	167	129	108	99	94	82
68.2	freezer	1,386	1,520	71	42	34	31	28	16
46.2	freezer	1,689	1,569	7	6	6	6	5	2
62.3	freezer	1,825	1,633	325	153	88	106	74	36
32.1	freezer	1,827	1,670	146	76	65	47	39	25
49.2	freezer	2,444	1,871	363	291	245	214	181	40
51.1	freezer	2,162	1,963	237	216	209	206	195	105
49.2	freezer		295	93	75	63	55	50	30
51.1	freezer		297	169	120	89	76	63	35
33.2	freezer		321	191	57	81	45	36	12
46.2	freezer		326	27	25	23	22	18	7
80.2	freezer		326	118	101	87	81	76	47
19.2	freezer		355	214	78	75	56	44	17
52.2	freezer		362	73	59	45	32	21	11
50.2	freezer		366	74	60	46	34	16	7
81.3	freezer		395	130	99	82	73	64	23
73.2	freezer		396	115	85	81	77	73	43
20.2	freezer		420	298	141	65	59	47	12
62.3	freezer		437	337	197	164	129	96	46
32.1	freezer		468	327	225	115	59	72	24
41.3	freezer		495	302	107	93	83	65	23
54.2	freezer		510	199	132	130	121	113	76
68.2	freezer		590	277	156	122	117	105	71
82.2	freezer		634	136	122	116	114	109	92

(1) This table presents data for existing and replacement appliances. Values in this column are blank for replacement appliances (no short-term metering was done on replacment appliances)

To assess the probability that the true annual consumption exceeds any given threshold, we calculated the portion of a normal curve with mean equal to the modeled long-term consumption, and standard deviation from the 'virtual period' that is above the threshold. For example, Figure 4.1 shows a normal distribution for a fictional refrigerator with average annual consumption of 1,500 kWh and a standard deviation of 300 kWh per year. The vertical line marks 1,825 kWh, (equivalent to 5 kWh per day). The area under the curve to the right of the vertical line represents 14% of the total area under the curve. Consequently, 14% of the readings for this particular refrigerator would exceed the threshold.

In this example,

energy savings = 0.14 * (pre consumption - post consumption)

cost to BEEP = 0.14 * ($50 + replacement appliance cost) + $15 + $20 if the short-term period exceeds 2 hours

where
        $15 = the cost to meter each appliance
        $50 = the administration cost of replacing the appliance
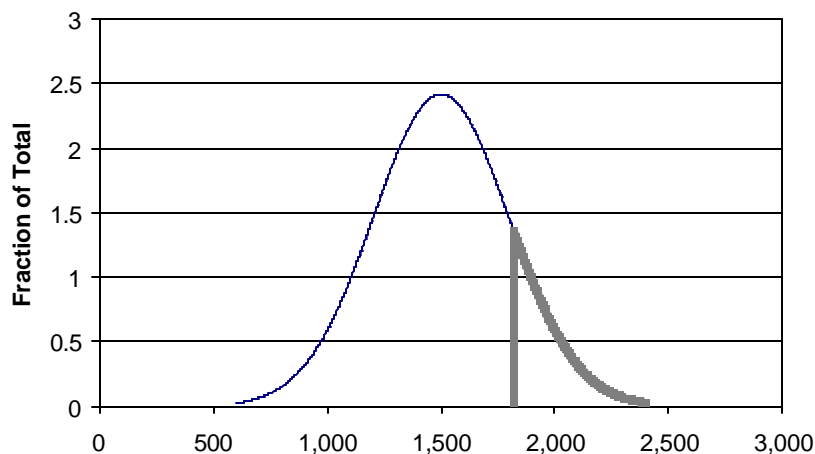 $20 = the cost to return to the residence to retrieve the meter

Figure 4.1. Probability of consumption above threshold

Extrapolating the data for the metered population to the client population
The appliances included in our long-term dataset are not representative of all of the appliances that were in use by the BEEP clients: the data represents only the appliances that met the replacement threshold based upon the 1-2 hour metering period and the replacement appliances. We had virtually no long-term data for appliances that consumed between approximately 3 and 4 kWh per day.

In order to reflect the mix of appliances encountered in the field, we first grouped the appliances into bins: refrigerators and freezers were grouped separately in increments of 400 kWh, centered around 1,800 kWh (approximately 5 kWh per day).

Next, we developed weighting factors to apply to each appliance within the bins so that the weighted values for the appliances would reflect the distribution of the annual consumption for all of the refrigerators and freezers in the population.

In order to develop the distribution of annual consumption, we needed an estimate of the annual consumption of each appliance encountered by the program. The estimated annual consumption was taken from the regression models where available. For all other appliances, we projected the annual consumption using the short-term metering data. We acknowledge two issues with using the short-term data to project annual consumption:

> 1) short-term metering is not a good basis for estimating annual consumption. Our analysis assumes that the error is random, so that those for which we overestimate consumption will be offset by those where it is underestimated, giving us a reasonable distribution overall; and

> 2) the short-term metering was done in summer (which is a period of greatest consumption due to the warmer, more humid conditions). We reduced the projected annual consumption by 7% to account for seasonally higher summer consumption.

Figures 4.2 and 4.3 show the distribution of annual consumption for refrigerators and freezers[9]. Superimposed on the charts is a log-normal distribution: we assigned our weighting factors as the proportion of area under the curve for each bin of the log-normal distribution.
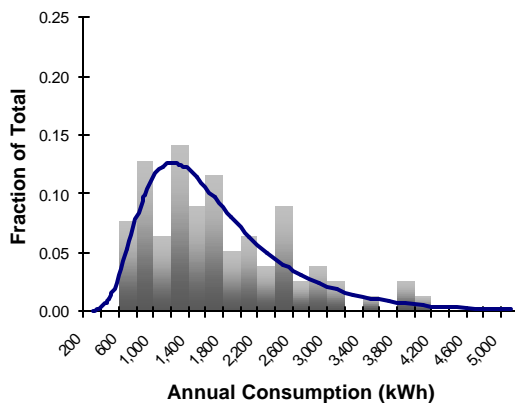
Figure 4.2. Refrigerator Energy Consumption
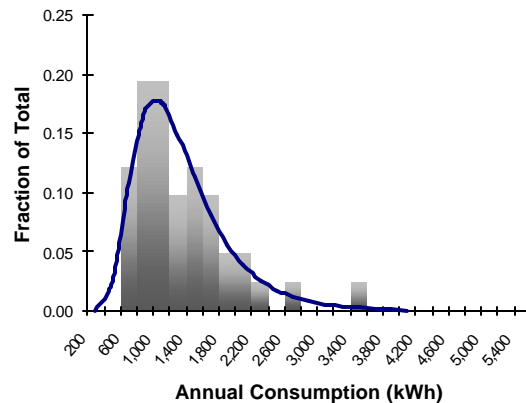
Figure 4.3. Freezer Energy Consumption

Program Costs
We calculated the cost-effectiveness assuming a $15 cost to conduct each assessment, and an additional $20 cost for retrieving meters left for longer than 2 hours (these are estimated costs from IWAP). We used the average cost of refrigerators and freezers installed by the program for our appliance cost. Finally, we assumed a program administration cost of $50 per replaced appliance.

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[9] We dropped several appliances from our data in order to develop representative distributions of the annual consumption. The estimated annual consumption for three refrigerators measured less than 400 kWh per year, one that exceeded 9,000 kWh per year, and one freezer had an estimated annual consumption of 61 kWh per year. The estimated consumption for these appliances was extrapolated from the short-term meter readings, and we believe that these are not reflective of actual consumption.

Results

We assessed the thresholds and metering lengths for three scenarios:

> 1) maximize savings for client savings to investment ratio (SIR),
> 2) maximize savings for the societal cost test benefit, and
> 3) maximize cost-effective program impacts.

We conducted the probabilistic assessment for a wide range of thresholds for refrigerators and freezers, from 1 to 10 kWh per day. In each scenario, we considered longer metering periods for appliances where the short-term readings are were very close to the thresholds, and conducted multiple runs to assess the best length for the short-term metering period.

Also for each scenario, we assessed impacts for appliance service lives of 6-20 years, in two year increments. The service lifetime is a key parameter for assessing the cost-effectiveness of the replacement appliances, with longer service lifetimes allowing for lower consumption thresholds. The results are very sensitive to assumptions of the service lifetime: the optimal thresholds increase substantially as the assumed service lifetime decreases. We estimated the weighted average service life was 15.5 years, roughly corresponding to sixteen years which we have highlighted in the table for each scenario.

We projected, for 100 households, the number of appliances installed, and the total costs and benefits.   In our assessment, the projected number of appliances replaced is smaller on a unit per household basis than what was achieved in the pilot program. A higher replacement rate was attained in the pilot program for the following reasons:

- the appliances were logged during the warmest, highest usage time of year, and consequently overestimated annual consumption
- several appliances that were replaced in the pilot did not meet the threshold, including 2 freezers and 4 refrigerators
- the short-term readings were extremely high for some of the appliances: the short-term readings were beyond 2 standard deviations for 33% of the freezers and 24% of the refrigerators, resulting in replacement of units which were below the usage thresholds. We are unaware of any systematic causes for such high consumption readings, however we observed that nearly all of these were metered for periods less than one and one-half hours in length.

Client Bill Savings

We assessed program impacts and the optimal thresholds by comparing client bill savings with the measure costs.   We assumed client bills would increase at the rate of inflation, and discounted all impacts using a rate of 5%. The thresholds were set to maximize total program benefits according to the following critieria:

- Individual appliance SIRs must equal or exceed 1.0, where the cost is equal to the average appliance cost along with the administration cost ($50)

- The overall program SIR must equal or exceed 1.0. Costs include the appliance costs, administration costs, and costs of metering

We modeled program impacts for two scenarios: in the first, we assumed a 2 hour metering period was used for all appliances; for the second, we assessed whether it was cost-effective to use a 24 hour metering period for some appliances (at an additional cost of $20 to retrieve the meter).

The upper half of Table 4.4 (Client Bill Savings section) shows the results. Values associated with a service lifetime of 16 years are highlighted, as this term most closely approximates our estimated service lifetime (15.5 years).

We found:

- The SIR is substantially above 1.0 for all reasonable service lives.

- Assuming a service life of 16 years, the optimal thresholds are considerably lower then those used in the pilot program, 4.2 versus 5.0 kWh per day for refrigerators, and 2.6 versus 4.0 used for freezers.

- Assuming a 16 year service life, for every 100 households, we project approximately 42 refrigerators and 23 freezers would be replaced given the thresholds determined in our analysis. We project that net benefits for the 16 year service life to approximate $34,136. First year client savings, over the entire 100 households, would average $75 per household.

In comparing the 2 hour with the 2/24 hour results we see:

- The thresholds are the same for both the 2 hour and 2/24 hour assessments.

- The 24 hour metering period was found to be cost-effective in some cases where the consumption exceeded the threshold. This suggests that it is used to weed-out those that showed atypically high consumption during the 2 hour metering period (such as during defrost cycles). It was not always cost-effective to meter the highest consumption appliances for more than 2 hours, however.

- Total benefits are about 5% greater using a mix of 2 hour and 24 hour metering periods.

- Net benefits are about 1% less for the 2/24 hour analyses, as measures closer to borderline cost-effectiveness are identified with the longer metering period.

- The number of freezer replacements remained about the same, but refrigerator replacements increased. Hence, most of the additional benefits accrued from longer metering on only the refrigerators.

Societal Cost Test
Utilities funding efficiency programs in Iowa must meet the societal cost test, which compares utility avoided costs (with a 10% adder) and measure costs. The benefit-to-cost ratio (BCR) must equal or exceed 1.0. The Iowa societal cost test is calculated using the utility avoided costs (energy and capacity) multiplied by 1.1 as benefits and costs defined as the total costs of the measure. Costs and benefits are discounted using the weighted average cost of capital. We used Alliant-IES avoided costs which include the 10% adder: $123.88 per kW, beginning in 1995 and escalated at 3.82%, average avoided energy costs of 1.8 cents in 1996, escalated at 3.82%

annually. Economic parameters included an inflation rate of 3.7%, and a weighted average cost of capital of 8.3%.

As in the previous analysis, we assessed program impacts and the optimal thresholds by comparing benefits with the measure costs. The thresholds were set to maximize total program benefits according to the following criteria:

- Individual appliance BCRs must equal or exceed 1.0, where the cost is equal to the average appliance cost along with the administration cost ($50).

- The overall program BCR must equal or exceed 1.0. Costs include the appliance costs, administration costs, and costs of metering.

As before, we modeled program impacts for two scenarios: for one we assumed a 2 hour metering period was used for all appliances, for the second, we assessed whether it was cost-effective to use a 24 hour metering period for some appliances (at an additional cost of $20 to retrieve the meter).

The lower half of Table 4.4 (Societal Cost Test section) shows the results.

In general, our results paralleled the results for the Client Bill Savings assessments, but with higher usage thresholds. The avoided costs are substantially lower than electricity rates, so that the usage thresholds must be set higher to assure cost-effective replacements. Notably, no threshold was cost-effective for service lifetimes of less than 10 years.

We found:

- Assuming a service life of 16 years, the optimal thresholds are higher than used in the pilot program for refrigerators, (6.1 versus 5.0 kWh per day), and lower for freezers (3.7 versus 4.0 kWh per day).

- Assuming a 16 year service life, for every 100 households, we project approximately 20 refrigerators and 11 freezers would be replaced given the thresholds determined in our analysis. This is roughly 45% of the appliances which we projected would be installed using the Client Bill Savings criteria.

In our review of the comparison of the 2 hour with the 2/24 hour results, we found:

- The thresholds are the same for both the 2 hour and 2/24 hour assessments.

- The 24 hour metering period was found to be cost-effective in some cases.

- For a sixteen year service life, total benefits are about 4% greater using a mix of 2 hour and 24 hour metering periods, and net benefits are about 10% less for the 2/24 hour analyses, as measures closer to borderline cost-effectiveness are identified with the longer metering period.

- Using the 2/24 hour metering method, the number of refrigerator and freezer replacements remained almost identical as the 2 hour-only method, with an additional unit or two provided by the 2/24 hour method.

Caveat

During the pilot program seven refrigerators were removed, but not replaced. In the analysis for this section of the report, we excluded savings for simple removals because our focus was on assessing thresholds for cost-effective appliance exchanges.

The BEEP program targets high-users of electricity, where multiple refrigeration appliances and/or high consumption refrigeration appliances are a likely contributor to high electricity use. If implemented concurrent with a traditional weatherization program, we should expect to find fewer high-use appliances per house than were encountered in the BEEP program. Although the usage thresholds would not change, the number of appliances replaced, and hence the average savings per household would probably be reduced from the $75 level which we modeled, and from the $85 per household attained in the pilot program. The prioritization criteria used to select IWAP clients could be designed to favor households with high electricity consumption, however the prioritization must also account for potential non-electric fuel use savings.

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Table 4.4 Results of the Analyses of Program Thresholds

serv life	refr	freezer	Total Benefits	Total Costs	Net Benefits	SIR (B/C)	refr	freezer	refr	freezer
			Projected Impacts per 100 Households				**Usage Threshold (kWh per day)**		**If 2 hour reading (extrapolated to the daily level) is in this range, then continue with 24 hour metering**	
Client Bill Savings										
2 hour metering period										
6	14	8	$18,094	$16,269	$1,825	1.11	6.8	4.1	#N/A	#N/A
8	22	14	$32,016	$24,814	$7,202	1.29	5.7	3.5	#N/A	#N/A
10	28	18	$45,461	$31,758	$13,702	1.43	5.1	3.1	#N/A	#N/A
12	34	20	$57,143	$36,544	$20,599	1.56	4.7	2.9	#N/A	#N/A
14	39	22	$68,452	$40,989	$27,462	1.67	4.4	2.7	#N/A	#N/A
16	42	23	$78,305	$44,169	$34,136	1.77	4.2	2.6	#N/A	#N/A
18	46	24	$87,722	$47,229	$40,493	1.86	4	2.5	#N/A	#N/A
20	47	26	$95,371	$48,964	$46,407	1.95	3.9	2.4	#N/A	#N/A
2 or 24 hour metering period										
6	15	9	$19,056	$17,638	$1,418	1.08	6.8	4.1	>7.1	3.8 -- 10.4
8	23	14	$33,379	$26,497	$6,883	1.26	5.7	3.5	>6.0	3.8 -- 10.4
10	31	20	$48,522	$35,250	$13,272	1.38	5.1	3.1	>4.9	2.7 -- 9.3
12	37	21	$60,316	$40,078	$20,238	1.50	4.7	2.9	>4.9	2.7 -- 9.3
14	41	23	$71,228	$44,071	$27,158	1.62	4.4	2.7	4.9 -- 10.4	2.7 -- 9.3
16	44	24	$81,230	$47,472	$33,758	1.71	4.2	2.6	3.8 -- 9.3	1.6 -- 8.2
18	48	25	$91,172	$51,132	$40,040	1.78	4	2.5	3.8 -- 8.2	1.6 -- 8.2
20	51	26	$99,392	$53,306	$46,086	1.86	3.9	2.4	3.8 -- 8.2	1.6 -- 8.2
Societal Cost Test										
2 hour metering period										
<12: no valid thresholds										
12	12	6	$14,991	$13,953	$1,038	1.07	7.1	4.3	#N/A	#N/A
14	16	10	$21,450	$18,488	$2,962	1.16	6.5	3.9	#N/A	#N/A
16	19	11	$26,412	$21,340	$5,072	1.24	6.1	3.7	#N/A	#N/A
18	22	14	$31,978	$24,814	$7,164	1.29	5.7	3.5	#N/A	#N/A
20	24	16	$36,822	$27,418	$9,404	1.34	5.5	3.3	#N/A	#N/A
2 or 24 hour metering period										
<12: no valid thresholds										
12	13	6	$16,082	$15,272	$810	1.05	7.1	4.3	>7.1	3.8 -- 11.5
14	16	10	$22,003	$19,384	$2,619	1.14	6.5	3.9	>6.0	3.8 -- 11.5
16	20	11	$27,594	$23,031	$4,563	1.20	6.1	3.7	>6.0	3.8 -- 8.2
18	23	14	$33,340	$26,633	$6,707	1.25	5.7	3.5	>6.0	3.8 -- 8.2
20	25	18	$38,647	$29,850	$8,797	1.29	5.5	3.3	>6.0	2.7 -- 7.1

Recommendations
By lowering the eligibility thresholds from those used in the pilot program, BEEP savings could be increased without compromising the overall program cost-effectiveness. Lowering the thresholds would have the dual impact of reducing lost opportunities and maximize cost-effective program savings.

Utilities expenditures are limited to measures that meet a relatively more restrictive societal cost test. To the extent that they are available, utility funds should be used for appliances which meet the societal test's usage thresholds. IWAP funds could be used for appliances that meet the client bill savings usage thresholds, including those appliances that do not meet the societal cost test.

We found that using a 24 hour metering period for some appliances would provide marginally higher total benefits and generally reduced net benefits. Although our analysis points to additional benefits from using 24 hour metering, we suspect that the complications involved with scheduling and completing a return visit to retrieve the meters might be not be worth the additional benefit. We suggest that a single, 2 hour metering period should be used for at least the initial year or two of program implementation. In practice, the meters should be placed on the appliances as soon as possible during the audit, and removed just prior to leaving the premises to assure the longest possible metering period is used.

Ideally, the thresholds would reflect seasonally variability: we observed some seasonality in refrigeration energy consumption, varying approximately $\forall$ 7%. We estimated seasonally differentiated thresholds to account for this.

Table 4.5 shows the recommended thresholds.

Table 4.5 Recommended Thresholds

Funding Source	Appliance Type	Single Annual Threshold (kWh per day)	Seasonally Variable Thresholds (preferable to the single annual threshold)	
			Summer (kWh per day)	**Moderate and Heating Season** (kWh per day)
WAP	Refrigerator	4.2	3.9	4.5
	Freezer	2.6	2.4	2.8
Utility	Refrigerator	6.1	5.7	6.5
	Freezer	3.7	3.4	4.0

This section contains additional results of our uncertainty analysis. All whole-house fuel impacts are broken out by the two major sources of error, i.e., sampling uncertainty and model parameter uncertainty. Each of these tables was calculated with a unique set of 10,000 runs.

Inspection of these tables reveals that sampling uncertainty is the dominate form of uncertainty in our analysis.

Computationally, the overall uncertainty is computed as the square root of the sum of the squares of the uncertainty in each component.

For example, the confidence interval for uncertainty for our median results of NAC for electricity in the pre-period was 14,227 to 15,714 (from Table 3.1). The standard deviation, which is approximated by the range (15,714-14,227) divided by (2*1.645), calculates to 452. Total uncertainty therefore is $452^2 = 204,282$.

Similarly, we can calculate the standard deviation from Table A.1 (sampling uncertainty) and Table A.2 (appliance regression uncertainty). We calculate these as 424 and 158 respectively. To compare these values with our overall model, we calculate: $424^2 + 158^2 = 204,740$. This value is very close to the value of 204,282 we found in our combined uncertainty model.

Table A.1. Uncertainty Derived From Sampling

Mean Value Results	Whole House Fuel Consumption				Savings							
	Pre-Period NAC		Post-Period NAC		Whole House		Refr/Freezer		Combined Educ/Misc Water Heater Mea		Water Heater Only	
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=75)	14,950	14,281 to 15,675	14,298	13,369 to 15,317	652	-33 to 1,344	0	0 to 0	652	-33 to 1,344		
Appliance only (n=14)	12,437	10,497 to 14,489	9,524	7,686 to 11,471	2,913	1,725 to 4,164	1,515	1,160 to 1,895	1,398	284 to 2,595		
Water heater, some with appliances (n=6)	13,388	11,364 to 15,583	8,486	6,196 to 10,830	4,902	3,080 to 7,206	574	147 to 1,067	4,328	2,428 to 6,803		
Net Appliance-only savings					2,393	1,111 to 3,723	1,515	1,160 to 1,895	877	-317 to 2,161		
Net Water heater, some appliances					4,382	2,466 to 6,673	574	147 to 1,067	3,808	1,796 to 6,284	2,930	650 to 5,587
Natural Gas (therms)												
Comparison (n=75)	1,001	896 to 1,112	1,024	914 to 1,140	-23	-57 to 11	0	0	-23	-57 to 11		
Appliance only (n=14)	1,015	856 to 1,171	1,025	904 to 1,138	-10	-70 to 54	0	0	-10	-70 to 54		
Water heater, some with appliances (n=6)	1,033	665 to 1,489	1,297	962 to 1,632	-264	-417 to -132	0	0	-264	-417 to -132		
Net Appliance-only savings					8	-57 to 77	0	0	8	-57 to 77		
Net Water heater, some appliances					-246	-395 to -114	0	0	-246	-395 to -114	-254	-415 to -111

Median Value Results	Pre-Period NAC		Post-Period NAC		Whole House		Refr/Freezer		Combined Educ/Misc Water Heater Mea		Water Heater Only	
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=47)	14,097	13,622 to 14,745	13,703	12,355 to 15,037	541	-428 to 988	0	0 to 0	541	-428 to 988		
Appliance only (n=8)	11,847	10,553 to 13,484	8,936	6,348 to 12,314	2,379	1,781 to 4,097	1,237	998 to 1,652	1,113	-77 to 2,096		
Water heater, some with appliances (n=4)	12,811	10,167 to 16,177	8,777	4,674 to 11,040	3,946	2,562 to 7,206	323	0 to 1,282	3,288	1,916 to 7,206		
Net Appliance-only savings					1,948	1,369 to 3,599	1,237	998 to 1,652	682	-414 to 1,783		
Net Water heater, some appliances					3,515	2,069 to 7,224	323	0 to 1,282	2,856	1,423 to 6,847	2,175	573 to 5,978
Natural Gas (therms)												
Comparison (n=47)	926	833 to 997	928	768 to 1,042	-23	-45 to 25	0	0	-23	-45 to 25		
Appliance only (n=8)	1,034	811 to 1,228	1,031	902 to 1,176	-28	-94 to 59	0	0	-28	-94 to 59		
Water heater, some with appliances (n=4)	910	491 to 1,822	1,306	682 to 1,895	-225	-531 to -74	0	0	-225	-531 to -74		
Net Appliance-only savings					-10	-80 to 78	0	0	-10	-80 to 78		
Net Water heater, some appliances					-207	-494 to -88	0	0	-207	-494 to -88	-197	-470 to -48

Table A.2 Uncertainty Derived From Regression Model Parameters

	Whole House Fuel Consumption				Savings							
Mean Value Results									**Combined Educ/Misc Water Heater Mea**		**Water Heater Only**	
	Pre-Period NAC		**Post-Period NAC**		**Whole House**		**Refr/Freezer**					
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=75)	14,950	14,687 to 15,208	14,298	14,142 to 14,455	652	345 to 953	0	0 to 0	652	345 to 953		
Appliance only (n=14)	12,437	11,996 to 12,889	9,524	9,376 to 9,671	2,913	2,451 to 3,381	1,515	759 to 2,281	1,398	511 to 2,315		
Water heater, some with appliances (n=6)	13,388	12,589 to 14,175	8,486	8,067 to 8,897	4,902	4,003 to 5,796	574	327 to 819	4,328	3,395 to 5,237		
Net Appliance-only savings					2,393	1,907 to 2,906	1,515	759 to 2,281	877	-18 to 1,810		
Net Water heater, some appliances					4,382	3,465 to 5,318	574	327 to 819	3,808	2,853 to 4,753	2,930	1,631 to 4,206
Natural Gas (therms)												
Comparison (n=75)	1,001	991 to 1,012	1,024	1,007 to 1,040	-23	-42 to -3	0	0	-23	-42 to -3		
Appliance only (n=14)	1,015	967 to 1,062	1,025	982 to 1,068	-10	-74 to 54	0	0	-10	-74 to 54		
Water heater, some with appliances (n=6)	1,033	1,015 to 1,051	1,297	1,259 to 1,336	-264	-307 to -222	0	0	-264	-307 to -222		
Net Appliance-only savings					8	-58 to 74	0	0	8	-58 to 74		
Net Water heater, some appliances					-246	-292 to -201	0	0	-246	-292 to -201	-254	-329 to -177
Median Value Results									**Combined Educ/Misc Water Heater Mea**		**Water Heater Only**	
	Pre-Period NAC		**Post-Period NAC**		**Whole House**		**Refr/Freezer**					
		90% CI		90% CI		90% CI		90% CI		90% CI		90% CI
Electricity (kWh)												
Comparison (n=47)	14,097	13,710 to 14,370	13,703	13,334 to 14,198	541	-48 to 754	0	0 to 0	541	-48 to 754		
Appliance only (n=8)	11,847	11,402 to 12,411	8,936	8,704 to 9,157	2,379	2,089 to 2,685	1,237	855 to 1,771	1,113	444 to 1,665		
Water heater, some with appliances (n=4)	12,811	12,285 to 13,230	8,777	7,865 to 9,411	3,946	2,679 to 5,039	323	0 to 567	3,288	2,216 to 4,212		
Net Appliance-only savings					1,948	1,684 to 2,549	1,237	855 to 1,771	682	108 to 1,480		
Net Water heater, some appliances					3,515	2,370 to 4,806	323	0 to 567	2,856	1,897 to 4,000	2,175	988 to 3,313
Natural Gas (therms)												
Comparison (n=47)	926	906 to 943	928	846 to 944	-23	-37 to 5	0	0	-23	-37 to 5		
Appliance only (n=8)	1,034	924 to 1,069	1,031	990 to 1,114	-28	-82 to 22	0	0	-28	-82 to 22		
Water heater, some with appliances (n=4)	910	890 to 930	1,306	1,242 to 1,369	-225	-256 to -195	0	0	-225	-256 to -195		
Net Appliance-only savings					-10	-71 to 38	0	0	-10	-71 to 38		
Net Water heater, some appliances					-207	-247 to -177	0	0	-207	-247 to -177	-197	-255 to -134

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